Programming Languages
(CS 550)
Lecture Summary
Object Oriented Programming and Implementation*

Jeremy R. Johnson

*Lecture based on notes from SICP
Theme

- Object oriented programming provides a convenient mechanism for modeling state. State is local to the object itself. Each object includes a set of functions (methods) through which its state can be accessed and changed.

- Inheritance is the major mechanism of object-oriented languages that allows sharing of data and operations among classes, as well as the ability to redefine these operations without modifying existing code (type polymorphism).

- Objects can be easily implemented in a language with first class functions (environments). Using the scheme interpreter we can incorporate these features in a language called TOOL.
Outline

- Review concepts of OOP
- Implementing objects in scheme
  - Store local state in environment
  - Use message passing for method invocation
  - Inheritance stores internally superclass
- Creating an object oriented language
  - TOOL (Tiny Object Oriented Language)
  - Extend metacircular interpreter to support classes, class instantiation, generic functions, and methods
Object Oriented Programming

- Classes
- Object instantiation (constructors)
- Instance variables
- Methods and method invocation
- Inheritance
  - Single and multiple inheritance
  - Abstract classes and dynamic binding
  - Subtype polymorphism
Modeling State in Scheme

(define (make-account balance)
  (define (withdraw amount)
    (if (>= balance amount)
        (begin (set! balance (- balance amount))
            balance)
        "Insufficient funds")
  (define (deposit amount)
    (set! balance (+ balance amount))
    balance)
  (define (dispatch m)
    (cond ((eq? m 'withdraw) withdraw)
          ((eq? m 'deposit) deposit)
          (else (error "Unknown request -- MAKE-ACCOUNT" m))))
  dispatch)

(define acc (make-account 100))
  ((acc 'withdraw) 50)
  50
  ((acc 'withdraw) 60)
  "Insufficient funds"
  ((acc 'deposit) 40)
  90
  ((acc 'withdraw) 60)
  30
Objects in Scheme

- An object is a procedure that, given a message as argument, returns another procedure called a method

```scheme
(define (get-method object message)
  (object message))

(define (make-speaker)
  (define (self message)
    (cond ((eq? message 'say)
           (lambda (stuff) (display stuff)))
           (else (no-method "SPEAKER"))))
  self)
```
Invoking a Method

- To ask an object to apply a method to some arguments we send the object a message asking for the appropriate method, and apply the method to the arguments:

```
(define (ask object message . args)
  (let ((method (get-method object message)))
    (if (method? method)
      (apply method args)
      (error "No method" message (cadr method))))
```
Example

(define george (make-speaker))
;Value: george

(ask george 'say '(the sky is blue))
(the sky is blue)
Inheritance

- One thing we may want to do is define an object type to be a kind of some other object type

```
(define (make-lecturer)
  (let ((speaker (make-speaker)))
    (define (self message)
      (cond ((eq? message 'lecture)
                (lambda (stuff)
                  (ask self 'say stuff)
                  (ask self 'say '(you should be taking notes)))
            (else (get-method speaker message))))
    self))
```
Example

(define gerry (make-lecturer))
;Value: gerry

(ask gerry 'say '(the sky is blue))
(the sky is blue)
;Unspecified return value

(ask gerry 'lecture '(the sky is blue))
(the sky is blue)(you should be taking notes)
;Unspecified return value
More Inheritance

- The following example shows a bug in the implementation (self is lost)

```
(define (make-arrogant-lecturer)
  (let ((lecturer (make-lecturer)))
    (define (self message)
      (cond ((eq? message 'say)
        (lambda (stuff)
          (ask lecturer 'say (append '(it is obvious that) stuff))))
          (else (get-method lecturer message))))
  self))
```
A Bug: Losing Self

- The problem is that when Albert calls internal lecturer, Albert’s self is lost. Albert, his internal lecturer, and his internal lecturer’s internal speaker, each have a self.

(define albert (make-arrogant-lecturer))

(ask albert 'say '(the sky is blue))
(it is obvious that the sky is blue)

(ask albert 'lecture '(the sky is blue))
(the sky is blue)(you should be taking notes)
Fixing the Bug

- We can fix this by changing the implementation so that all the methods keep track of self by taking self as an extra input.

```scheme
(define (make-speaker)
  (define (self message)
    (cond ((eq? message 'say)
            (lambda (self stuff) (display stuff)))
          (else (no-method message))))
  self)

(define (ask object message . args)
  (let ((method (get-method object message)))
    (if (method? method)
        (apply method (cons object args))
        (error "No method" message (cadr method))))
```
Multiple Inheritance

- We can have object types that inherit methods from more than one type

```
(define (make-singer)
  (lambda (message)
    (cond ((eq? message 'say)
             (lambda (self stuff)
                (display (append '((tra-la-la --) stuff))))))
     ((eq? message 'sing)
      (lambda (self)
        (display '((tra-la-la))))
     (else (no-method "SINGER"))))
```
Multiple Inheritance (singer/lecturer)

(define ben
  (let (((singer (make-singer))
          (lecturer (make-lecturer)))
    (lambda (message)
      (let (((sing (get-method singer message))
               (lect (get-method lecturer message)))
        (if (method? sing)
            sing
            lect))))))

(ask ben 'sing)
(tra-la-la)
(ask ben 'say '(the sky is blue))
(tra-la-la -- the sky is blue)
(ask ben 'lecture '(the sky is blue))
(tra-la-la -- the sky is blue)
(tra-la-la -- you should be taking notes)
Multiple Inheritance (lecturer/singer)

(define alyssa
  (let ((singer (make-singer))
       (lecturer (make-lecturer)))
    (lambda (message)
      (let ((sing (get-method singer message))
            (lect (get-method lecturer message)))
        (if (method? lect)
            lect
            sing))))

(ask alyssa 'sing)
(tra-la-la)

(ask alyssa 'lecture '(the sky is blue))
(the sky is blue)(you should be taking notes)
TOOL Overview

- Define classes
  - `(define-class name superclass . slots)`

- Instantiate classes
  - `(make class slot-names-and-values)`

- Generic functions (dispatch on signature)
  - `(define-generic-function name)`

- Method definition
  - `(define-method generic-function (params-and-classes . body))`
TOOL Examples

(load "teval")
;Loading "teval.scm"... done
;Value: set-binding-value!

(initialize-tool)

TOOL==> (define-class <cat> <object> size breed)
(defined class: <cat>)

TOOL==> (define garfield (make <cat> (size 6) (breed 'wierd)))
*undefined*

TOOL==> (get-slot garfield 'breed)
wierd

TOOL==> (get-slot garfield 'size)
6
TOOL Examples

TOOL==> (define-generic-function 4-legged?)
(defined generic function: 4-legged?)

TOOL==> (define-method 4-legged? ((x <cat>)) true)
(added method to generic function: 4-legged?)

TOOL==> (4-legged? garfield)
#t

TOOL==> (define-method 4-legged? ((x <object>)) 'who-knows)
(added method to generic function: 4-legged?)

TOOL==> (4-legged? 3)
who-knows
TOOL Examples

TOOL==> (define-generic-function say)
(defined generic function: say)

TOOL==> (define-method say ((x <cat>) (stuff <object>))
   (print 'meow:)  (print stuff))
(added method to generic function: say)

TOOL==> (define-class <show-cat> <cat> awards)
(defined class: <show-cat>)

TOOL==> (define-method say ((cat <show-cat>) (stuff <object>))
   (print stuff)
   (print '(I am beautiful)))
(added method to generic function: say)
TOOL Examples

TOOL==> (define Cornelius-Silverspoon-the-Third
         (make <show-cat>
             (size 'large)
             (breed '(Cornish Rex))
             (awards '((prettiest skin)))))
         *undefined*
TOOL==> (say Cornelius-Silverspoon-the-Third '(feed me))
       (feed me)
       (i am beautiful)
       #!unspecific
TOOL==> (define-method say ((cat <cat>) (stuff <number>))
       (print '(cats never discuss numbers)))
       (added method to generic function: say)
TOOL==> (say fluffy 37)
       (cats never discuss numbers)
       #!unspecific
TOOL Implementation

- Extend metacircular interpreter to handle class, generic function, and method definitions, and instance creations

- Provide code to apply a generic function
Modified Scheme Interpreter eval

(define (tool-eval exp env)
  (cond ((self-evaluating? exp) exp)
       ((quoted? exp) (text-of-quotation exp))
       ((variable? exp) (lookup-variable-value exp env))
       ((definition? exp) (eval-definition exp env))
       ((assignment? exp) (eval-assignment exp env))
       (;;((lambda? exp) (make-procedure exp env))
       ((conditional? exp) (eval-cond (clauses exp) env))
       ((generic-function-definition? exp)
        (eval-generic-function-definition exp env))
       ((method-definition? exp) (eval-define-method exp env))
       ((class-definition? exp) (eval-define-class exp env))
       ((instance-creation? exp) (eval-make exp env))
       ((application? exp)
        (tool-apply (tool-eval (operator exp) env)
                    (map (lambda (operand) (tool-eval operand env))
                         (operands exp))))
       (else (error "Unknown expression type -- EVAL >> " exp)))))
Modified Scheme Interpreter

apply

(define (tool-apply procedure arguments)
  (cond ((primitive-procedure? procedure)
          (apply-primitive-procedure procedure arguments))
        ((compound-procedure? procedure)
          (eval-sequence
           (procedure-body procedure)
           (extend-environment (parameters procedure)
                                arguments
                                (procedure-environment procedure))))
        ((generic-function? procedure)
          (apply-generic-function procedure arguments))
        (else (error "Unknown procedure type -- APPLY"))))
TOOL Data Structures

- **Class**
  - Class name, list of slots, list of ancestors

- **Generic function**
  - Name, list of methods defined for function

- **Method**
  - Specializers, procedure

- **Instance**
  - Class, list of values for slots
Defining Generic Functions

(define-generic-function name)

(define (eval-generic-function-definition exp env)
  (let ((name (generic-function-definition-name exp)))
    (let ((val (make-generic-function name)))
      (define-variable! name val env)
      (list 'defined 'generic 'function: name))))
Defining Methods

\[(\text{define-method} \ \text{generic-function} \ (\text{params-and-classes}) \ . \ \text{Body})\]

\[
\begin{align*}
&\text{(define (eval-define-method exp env)} \\
&\quad (\text{let } ((\text{gf} \ (\text{tool-eval} \ (\text{method-definition-generic-function} \ \text{exp}) \ \text{env})))) \\
&\quad (\text{if } (\text{not } (\text{generic-function?} \ \text{gf})) \\
&\quad \quad (\text{error } "\text{Unrecognized generic function -- DEFINE-METHOD >> }"
&\quad \quad \quad (\text{method-definition-generic-function} \ \text{exp}))) \\
&\quad (\text{let } ((\text{params} \ (\text{method-definition-parameters} \ \text{exp})))) \\
&\quad (\text{install-method-in-generic-function} \\
&\quad \quad \text{gf} \\
&\quad \quad (\text{map } (\lambda (p) \ (\text{paramlist-element-class} \ p \ \text{env})) \ \\
&\quad \quad \quad \text{params}) \\
&\quad \quad (\text{make-procedure} \ (\text{make-lambda-expression} \\
&\quad \quad \quad \quad (\text{map} \ \text{paramlist-element-name} \ \text{params}) \\
&\quad \quad \quad \quad (\text{method-definition-body} \ \text{exp}) \\
&\quad \quad \quad \quad \text{env})) \\
&\quad \quad (\text{list 'added 'method 'to 'generic 'function:} \\
&\quad \quad \quad (\text{generic-function-name} \ \text{gf}))))))))
\end{align*}
\]
Defining and Instantiating Classes

(define-class name superclass . Slots) (make class slot-names-and-values)

(define (eval-define-class exp env)
  (let ((superclass (tool-eval (class-definition-superclass exp) env)))
    (if (not (class? superclass))
      (error "Unrecognized superclass -- MAKE-CLASS >> "
        (class-definition-superclass exp))
    (let ((name (class-definition-name exp))
        (all-slots (collect-slots (class-definition-slot-names exp) superclass)))
      (let ((new-class (make-class name superclass all-slots)))
        (define-variable! name new-class env)
        (list 'defined 'class: name))))
Applying Generic Functions

- Find all methods that are applicable
- Use first one (most specialized)
  - Method1 < Method2 (class method1 is a subclass of class method2)
- Extract procedure for that method and apply

(define (apply-generic-function generic-function arguments)
  (let ((methods (compute-applicable-methods-using-classes
                  generic-function
                  (map class-of arguments))))
    (if (null? methods)
      (error "No method found -- APPLY-GENERIC-FUNCTION")
      (tool-apply (method-procedure (car methods)) arguments))))
(define (compute-applicable-methods-using-classes generic-function classes)
  (sort
   (filter
    (lambda (method)
      (method-applies-to-classes? method classes))
    (generic-function-methods generic-function))
  method-more-specific?))

(define (method-applies-to-classes? method classes)
  (define (check-classes supplied required)
    (cond ((and (null? supplied) (null? required)) true)
      ;; something left over, so number of arguments does not match
      ((or (null? supplied) (null? required)) false)
      ((subclass? (car supplied) (car required)) ;; class1 is subclass of class2 if
       (check-classes (cdr supplied) (cdr required))) ;; class2 in ancestor list of class1
      (else false)
    ))
  (check-classes classes (method-specializers method)))
Assignment 7

- Extend assignment 6 (mini language with first class functions) to support classes, objects, and inheritance
  - Class name \((p_1, \ldots, p_n)\)
    
    ```text
    <stmt-list>
    End
    ```
  - The statement list defines the methods \((\text{method}_1, \ldots, \text{method}_n)\) and attributes in the class
  - The class definition provides a constructor with parameters \(p_1, \ldots, p_n\), called by name\((p_1, \ldots, p_n)\). The constructor returns an object which can access the methods and attributes of the class initialized by the constructor using the familiar dot notation.
Example

Class list(init)
L := init;
Cons := proc(x) return cons(x,L) end;
Car := proc() return car(L) end;
Cdr := proc() return cdr(L) end;
end;

L := list([]);
L.Cons(3);
L.Cons(2);
L.Cons(1);
x := L.Car(); // = 1
M := L.Cdr(); // = [2,3]
Assignment 7

- Inheritance
  - Classes can be derived from other classes using the notation

  \[
  \text{Class name}(p_1, \ldots, p_n) : \text{supername} \\
  \text{<stmt-list>}
  \text{End}
  \]

  - Objects in the derived class should be able to access methods and attributes from the derived class, however, they can be redefined in the subclass.